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A Comparative Evaluation of the Effect of Three Different Connector Designs in Predicting Fracture Resistance of Metallic, Metal-Ceramic and All-Ceramic Core Full Coverage Four Unit Bridge

A Finite Element Analysis

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Abstract

Aim: Purpose of this study is to compare and evaluate the effect of three different connector designs in predicting fracture resistance of Metallic, Metal-ceramic and All Ceramic full coverage four unit bridge by using Finite Element Analysis.

Materials and Method: A three dimensional model of a four unit bridge in the fourth quadrant was fabricated. These bridges were designed with 3 different materials and 3 different connector designs. A load of 500N was applied onto the pontics and the probability of fracture resistance was assessed using Finite element analysis.

Results: Metallic bridge with circular connector had the highest fracture resistance compared to other connector designs.

Conclusion : Metallic bridge with circular connector had the highest fracture resistance compared to others due to more surface area and All- ceramic bridge with triangular connector had the lowest fracture resistance due to less surface area.

Keywords
Connector, Finite element analysis, Fracture resistance, Magnitude, Von-mises stress

INTRODUCTION

The fixed partial denture (FPD) is a fixed dental prosthesis that replaces one or more missing natural teeth and restores its function and appearance; it cannot be removed from the mouth by the patient. Natural teeth or roots provide the primary support. Abutment teeth are those that provide support for the bridge. A pier abutment is an abutment that has edentulous space on both sides.[1] A component of FPD that helps the prosthesis remain in place by taking support from the abutment tooth is a retainer. On a fixed prosthetic denture, a pontic is an artificial tooth that replaces a missing natural tooth, restores its function, and typically fills the space left by the natural tooth. The portion of a fixed partial denture that joins the retainer and pontic is referred to as the connector in fixed prosthodontics. Connectors are the components of a fixed partial denture (FPD) or splint that join the individual retainers and pontics together. Rigid and non-rigid connectors are typically used to do this. A medium is required in order to join two things.[2] While a non-rigid connector permits limited movement between distinct segments of the fixed partial denture prosthesis, a rigid connector constitutes a solid, soldered, or fused connection linking the retainer and pontic.[3] Non-rigid connectors are often utilized to accommodate fixed partial denture abutments that are misaligned or to ease stress. Loop connectors or spring cantilever designs are employed to maintain an existing diastema when a fixed prosthesis is intended.[4] It is made up of a loop connecting adjacent retainer or pontics on the lingual portion of the prosthesis.

Three key factors determine the success of a fixed dental restoration: marginal fit, biomechanical behaviour (wear and fracture resistance), and aesthetics. These criteria demand extremely high requirements on the restoration material. Due to zirconia's superior aesthetics, it has gained popularity as a metal substitute for fixed dental prosthesis.[5,6] Above all, zirconia is more resistant to wear than alloys and metal.[7] The improved mechanical qualities of polyether ether ketone (PEEK) make it a suitable substitute material for zirconia. Moreover, PEEK is far less abrasive than zirconia. PEEK has consistent physical and chemical characteristics.[8] resistance to the majority of chemicals, with the exception of concentrated sulfuric acid, wear resistance, and stability at high temperatures (such as during sterilization procedures).[9]

Research on the mechanical behavior of fixed partial dentures (FPDs) has oftentimes revealed that the connector region experiences the highest tensile stress values when load is applied at the pontic central region. Regardless of the material selected, the connector region is thought to be the weakest part of the prosthesis and has the highest risk of breaking.

When load is applied at the pontic central region, research on the mechanical behavior of fixed partial dentures (FPDs) has frequently shown that the connection region encounters the highest values of tensile stress. The connector region is regarded as the weakest and most likely to break section of the prosthesis, regardless of the material chosen .[10]

Since its position and design determine the prosthesis's success, connectors are the smallest and most carefully designed components of an FPD. There are various connector types available to choose from, depending on the prosthetic requirements and clinical situations. Depending on the operator's preference and the length of the span, a soldered or cast connection may be chosen. The success of the fixed partial denture will be determined and influenced by the connector's size, shape, and placement.

AIM

Purpose of this study is to compare and evaluate the effect of 3 different connector designs in predicting fracture resistance of Metallic, Metal-ceramic and All Ceramic full coverage 4 unit bridge by using Finite Element Analysis.

OBJECTIVES

1) To evaluate the effect of connector designs in predicting fracture resistance of 4 unit Metallic bridge by Finite element analysis.
2) To evaluate the effect of connector designs in predicting fracture resistance of 4 unit Metal-Ceramic bridge by Finite element analysis.
3) To evaluate the effect of connector designs in predicting fracture resistance of 4 unit All Ceramic bridge by Finite element analysis.

MATERIALS AND METHODOLOGY

An analysis of the scenario was conducted using a three-dimensional finite element research to generate models featuring varying materials and connector designs. In order to predict the fracture resistance on the different connectors in various materials, finite element analysis was used.

Materials

1. All metal (Co-Cr)
2. Metal ceramic (Feldspathic porcelain)
3. All ceramic (Lithium disilicate)

All materials differ in properties such as density, poisson's ratio, Young's modulus and tensile strength as seen in Table 1.

Table 1 Properties of different materials

Material	Density(g/cm^3)	Poison's ratio (μ)	Young's modulus (Gpa)	Ultimate tensile strength (MPa)
Metal (Co-Cr)	8.6		200	900
Metal- ceramic (feldspathic porcelain)	2.8	0.3	75	600
All-Ceramic (lithium disilicate)	2.6	0.25	80	400

Connector Designs

1. Circular
2. Elliptical
3. Triangular

Cross sectional views of different connectors can be seen in Fig. 1.

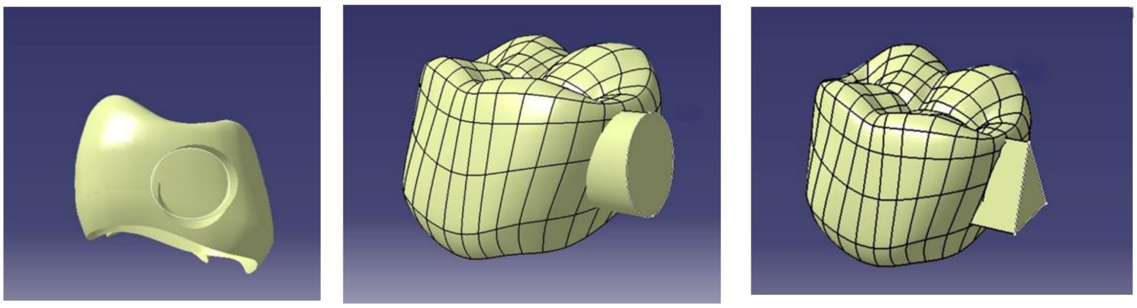

Fig. 1 Cross sectional view of circular, elliptical and triangular connectors

TEETH DESIGNING PROCEDURE

A three dimensional model of a four unit bridge of the fourth quadrant in the mandible was fabricated such that retainers to be 44 and 47 & pontics to be 45 and 46.

Four unit bridges were designed with 3 different materials and 3 different connector designs.

The following configurations were the subjects of the construction of three-dimensional finite element models

Model 1: All metal 4 unit bridge with circular connectors
Model 2: All metal 4 unit bridge with triangular connectors
Model 3: All metal 4 unit bridge with elliptical connectors
Model 4: Metal- ceramic 4 unit bridge with circular connectors
Model 5: Metal- ceramic 4 unit bridge with triangular connectors
Model 6: Metal- ceramic 4 unit bridge with elliptical connectors
Model 7: All ceramic 4 unit bridge with circular connectors
Model 8: All ceramic 4 unit bridge with triangular connectors
Model 9: All ceramic 4 unit bridge with elliptical connectors

SYSTEM CONFIGURATIONS

The computational numerical analysis was done using designing software Catia V5, meshwork ANSYS version 15.0, hard disk of 1000 GB, Windows edition X, processor i7 and RAM of 8GB.

Load applied

An axial load of 500N was applied on the central fossae of the pontics of these final element models (Fig. 2).

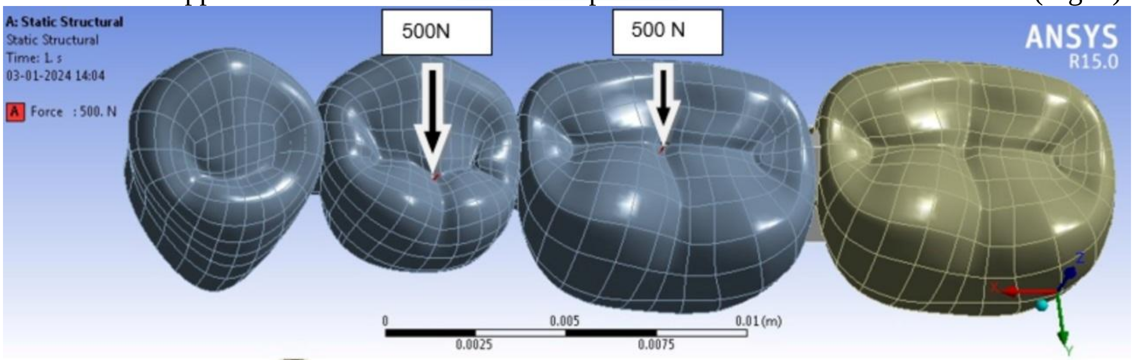

Fig. 2 A total load of 500N being applied on the central fossae of the pontics

RESULTS

The present study evaluated the probability of fracture resistance of nine finite element models which are grouped into 3 different categories:

Group I consisted of models on which 500N axial loads of magnitude was applied on the pontics with circular connector design of All metal, metal ceramic and All ceramic 4 unit bridges.

Group II consisted of models on which 500N axial loads of magnitude was applied on the pontics with elliptical connector design of All metal, metal ceramic and All ceramic 4 unit bridges.

Group III consisted of models on which 500N axial loads of magnitude was applied on the pontics with triangular connector design of All metal, metal ceramic and All ceramic 4 unit bridges.

Each model's principal and peak Von Mises stresses were investigated in order to determine the fracture resistance (Fig. 3).

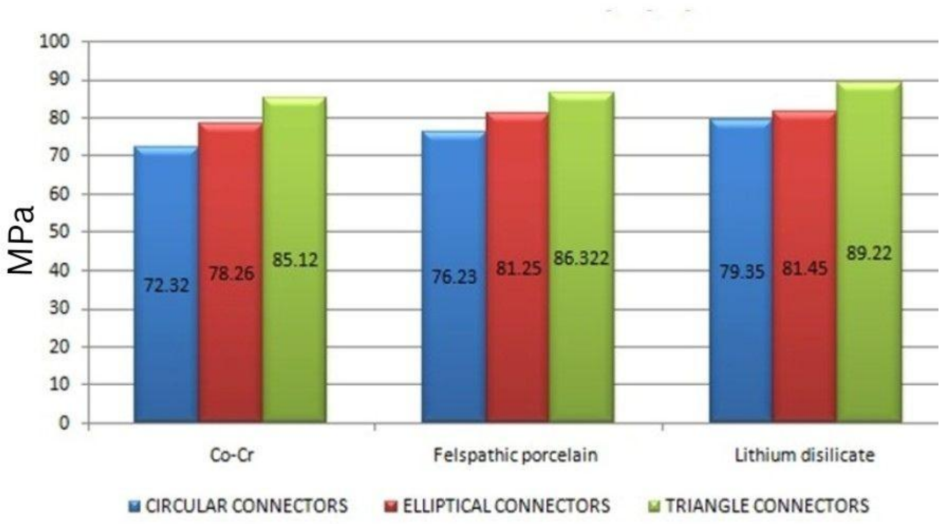

Fig. 3 Overall representation of maximum Von-Mises stress

For a metallic bridge with circular connectors, von mises stress value was noted to be 72.32 Mpa which was the lowest of all the other models. This indicated that metallic bridge with circular connector had the highest fracture resistance compared to others.

For an All -ceramic bridge with triangular connectors, von mises stress value was noted to be 89.22 Mpa which is the highest among other models. This indicated that All- ceramic bridge with triangular connector had the lowest fracture resistance compared to others.

DISCUSSION

In order to connect individual crowns or pontics to create a stable and functional restoration, connectors are frequently needed for fixed dental prostheses in prosthodontics. The success and durability of the prosthesis are greatly influenced by the connector selection. While choosing the right type of connector, a number of aspects must be taken into account, including aesthetics, biomechanics, and ease of construction.

The aesthetic factor is one of the most significant aspects in connector design. In order to replicate the natural dentition, connectors should appear to blend in perfectly with the surrounding teeth and soft tissues. Therefore, attaining a harmonious appearance depends critically on the size, shape, and placement of connectors. A more subtle and discreet connector design is frequently chosen in the anterior area, where aesthetics are crucial.

Another important factor that affects the choice of connector is biomechanics. In order to reduce stress and avoid issues like fractures of the abutment teeth, the connection must distribute occlusal stresses equally throughout the supporting teeth. The force transmission is greatly influenced by the type of connector. A more flexible connector design may be recommended to disperse stresses in circumstances where a rigid connector would place undue stress on the abutment teeth.

The maintenance of the prosthesis's oral hygiene is also influenced by connector design. For easier access and cleaning, appropriate contouring and connector spacing are crucial. Connectors that are poorly made can cause food impaction, accumulation of plaque, and gingival irritation, all of which can be detrimental to the supporting tissue's health.

The fabrication process and material selection for connectors are essential considerations. The material of choice needs to have the right amount of flexibility and strength to support functional loads. In fixed dental prosthesis, connectors are essential to the restoration's success. In connector design, aesthetics, biomechanics, convenience of production, and oral maintenance must all be carefully taken into account.

In this experimental dissertation, 3 connector designs – circular, elliptical and triangular have been modelled on 4 unit bridges made of 3 different materials – Metal, Metal -ceramic and All ceramic. Furthermore, all those models have been subjected to a total force of 500N.

Results might differ for the persons with parafunctional habits as the force applied on the teeth will be higher. Charles H Gibbs et al (1986)[11] in his study concluded that bite strength in some bruxer-clenchers can reach up to six times that of non-bruxers which could be around 975 lbs. Hence in the present study, an average load of 500 N was applied.

The primary objective of this research was to predict the fracture resistance of various connector designs in a 4 unit bridge made of three different materials- Metal, Metal-ceramic and All ceramic. Clinicians can assess and formulate an appropriate treatment strategy based on the results of this finite element research.

Regardless of the material, it is preferable to increase the cross sectional area of the framework connector to maximize the survival of FPD restoration. For all ceramic systems, the connector dimensions of 3 x 3 mm and 4 x 4 mm were suggested. Therefore, 4x4mm was selected as the connector's dimension in this investigation.

With regards to the cross sectional design of the connector, Tuli et al stated that the maximum stress concentration was seen with circular cross sectional design while the least was with inverted T shape connector. In the present study, maximum stress concentration was seen with triangular connector while the least was with circular connector.

A connector dimension of 4 x4 mm with circular, elliptical and triangular cross section were used. The results showed that stress concentrations were observed within or near the connectors. All metal bridge with circular connectors showed high fracture resistance while K Onodera et al (2010) [12] in his study concluded that no significant difference in fracture load was observed between any two shapes of connector (circular & oval). But in terms of cross sectional area, there was a statistically significant difference in the fracture load between 9, 7 and 5 mm^2.

Won-suck Oh (2002) in his study stated that clinical crowns are uniformly supported by a complex combination of materials and microstructural factors, including the cement layer. This bonding characteristic may affect the fracture resistance and the failure mode of ceramic restorations by altering the stress distribution through the substructure and reducing stress concentrations adjacent to internal surface flaws in the ceramic material.[13] The elastic modulus of the supporting structure also is an important factor that controls stress distribution.[14]

Sepideh Mokhtarikhoee[15] et al in his study concluded that maximum stress occurred in the connector area in all models which is same in the present study also.

According to a study done by Lakshmi RD et al materials were able to sustain a force of up to 500 N when the connector dimensions were increased to 4 mm x 4 mm, replicating the maximum posterior bite force. Hence a total load of 500N was applied.

In their investigation, Singh MS et al discovered that the circular cross-sectional design displayed the highest level of stress concentration, while the inverted T-shaped connector displayed the least. Consequently, the study found that the connector area of a three-unit bridge had the highest concentration of stress. This modification to the cross-sectional design of the connector affects all ceramic fixed partial dentures. The current study also found that altering the connector's cross sectional design had an impact on the maximum stress concentration in a four-unit bridge made of all the materials. Different materials may exhibit different relationships between Von Mises stress and fracture resistance. Brittle materials, for example, may have a more direct relationship between stress and fracture, while ductile materials may exhibit a more complex interplay between stress, strain, and fracture. Hence all the material properties of different materials were taken into consideration.

For a metallic bridge with circular connectors, von mises stress value was noted to be 72.32 Mpa which was the lowest of all the other models. This indicated that metallic bridge with circular connector had the highest fracture resistance compared to others due to more surface area.

For an All -ceramic bridge with triangular connectors, von mises stress value was noted to be 89.22 Mpa which is the highest among other models. This indicated that All- ceramic bridge with triangular connector had the lowest fracture resistance compared to others due to less surface area.

Finite element analysis has shown to be an extremely accurate and precise method of analysing structures. But living structures are more than simply material objects. Finite Element analysis relies on mathematical calculations based on a computer-generated model of the framework and its surrounds.[16]

However, biology is not a determined field, and live tissues cannot be reduced to preset parameters and values. Because of this, finite element analysis should not be employed primarily, even though it provides a strong theoretical framework for understanding how a building would react in a given situation. To ascertain the true nature of the biologic system, real experimental procedures and clinical trials ought to be conducted after finite element analysis. The sample that was taken in this study doesn't follow Antes law. For PFM – only the outer layer made of porcelain was considered. Although the final values might not be precise in terms of numbers, they are usually acknowledged in terms of quality.

CONCLUSION

It is possible to conclude, within the parameters of the current investigation, that Metallic bridge with circular type of connectors has the highest fracture resistance and All-ceramic bridge with triangular type of connectors has the lowest fracture resistance.

All the circular connectors have high fracture resistance irrespective of the materials that have been used while triangular connectors having the lowest.

This is due to increased surface area contributes to greater fracture resistance while decreased surface area corresponds to lower fracture resistance.

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